the ripple index is approximately constant and is independent of flow intensity. For medium-grained sand statistical properties of the ripples and dunes other than the ripple index are required to correlate the characteristics of the bed configurations with flow parameters.

Two methods of analysis for medium sand have been developed. In the first, spectral analyses of profiles of the channel bed lead to a linear second-order Markov model which describes the essential statistical properties of the dunes. All the parameters of the model are simple linear functions of the water discharge per unit width of channel. One of the parameters, the standard deviation of the bed elevation about the mean, shows excellent correlation (correlation coefficient of 0.99) with unit water discharge for flows ranging from 0.7 to 10 cfs. per foot of width and for average dune lengths from 2–25 feet.

The second method of analysis consists of defining distributions of dune lengths, amplitudes, ripple indices, and angles of downstream faces, and relating the moments of these distributions to flow characteristics. All the distributions are skewed, and the skewness correlates roughly with flow intensity. This analysis gives useful indications of the variations in the geometric properties of ripples and dunes, but it is time-consuming and requires extensive data. Moreover, the parameters describing the ripples and dunes show only a crude relation to flow characteristics. Of the two methods, the spectral analysis appears to be more useful.

OSBORNE, ROBERT H., Department of Geology, University of Southern California, Los Angeles, Calif.

*R*-MODE FACTOR ANALYSIS OF CINCINNATIAN (UPPER ORDOVICIAN) LIMESTONES

An *R*-mode factor analysis based on 20 petrographic variables observed in thin sections of 60 Cincinnatian biomicrosparrudites was made to determine genetic relations among several limestone classes. Thin sections were used for point-count estimates of whole and broken brachiopod grains, whole and broken bryozoan grains, disarticulated crinoid columnals, whole gastropods, and broken trilobite carapaces, as well as matrix (micrite and enclosed dolomite) and sparite. The correct volume of each measured variable lies within 5 per cent on each side of the obtained value with a 95 per cent confidence. The weight percentage of insoluble residue contained in each limestone sample also was determined. These measurements were combined into a $20 \times 60$ data matrix. The product-moment correlation coefficient was computed for each pair of variables, and the results were arranged in a $20 \times 20$ correlation matrix. Five statistically significant factors were extracted from the correlation matrix, which account for 82 per cent of the total variance. The geologic interpretations of the factor axes in order of extraction (decreasing significance) are: (1) mechanical energy gradient at the depositional site, (2) substrate firmness, (3) degree of lithification, (4) relative contributions of carbonate mud and skeletal grains to the sediment, and (5) Eh at or slightly below the depositional interface.

PAYNE, MAX B., Worldwide Geothermal Exploration Company, Los Angeles, Calif.

STRATIGRAPHY OF PRODUCING GEOTHERMAL FIELDS

Natural steam production is found in reservoir rock overlain by impervious cap rock. These rocks may be volcanic, sedimentary, metamorphic, or plutonic. The age and composition of these rocks are not important but only Pliocene and Recent magmas are known as an underlying heat source. Reservoir rocks usually are highly fractured and rendered porous by solutions, must be of sufficient thickness (minimum 100 meters), and of an areal extent to sustain continuous production. Porosity values should be at least 10 per cent.

Man has utilized natural steam and hot waters throughout historic time. There are many present-day uses for natural heat, such as wood-pulp manufacture, evaporation of salt, space heating, and greenhouse farming. The first electricity made from natural steam was in 1905 at Larderello, Italy. Iceland, New Zealand, and Japan also were early users of geothermal energy. The Geysers in California is the first and only geothermal field generating electricity in the United States. Pacific Gas and Electric installed the first 12,000-kwh. turbine-generator in 1960, a 14,000-kwh. unit in 1963, and in 1966 installed a 27,500-kwh. unit for a total of 53,500-kwh. capacity. A fourth unit is planned in 1968 bringing the total to 81,000 kwh. The rapid industrialization and population growth of the western states, as well as the world, has led to increased demands for energy. The U.S. Bureau of Mines Circular 8230 states that, if the growth in electric energy consumption occurs as projected, construction of considerably more thermal-generating plants will be required. Natural steam probably is the cheapest source of energy.

Potential geothermal resources of steam are evacuated by five fundamental criteria: (1) source of heat; (2) regional and local structural features; (3) source of meteoric waters (to infiltrate and circulate to depth); (4) reservoir rock sufficient to retain geothermal fluids in volume; and (5) impervious cap rock overlying reservoir for trapping steam.

Facca and ten Dam recommend exploration in four stages:

1. Preliminary survey and selection of area (includes geological, geophysical, and geothermal information, stratigraphic studies, and porosity and permeability data).
2. Detailed survey of selected area (includes photogeology, volcanological and petrographic studies, hydrogeochemistry, and hydrogeology and gradient surveys).
3. Test drilling.
4. Probing and evaluating (includes output measurements and production tests).

Stratigraphic data of three producing geothermal fields for comparison are given.

*Larderello field, Tuscany, Italy,* discussed by Facca (1963). He described the sequence and conditions as follows: (1) basement rock, quartzitic and anagenetic; (2) reservoir rock, evaporitic dolomite with high porosity and permeability, Late Triassic; (3) cap rock, flysch-like, shaly, impervious *argille scagliose*, Late Cretaceous-early Miocene age; (4) no Recent volcanoes; (5) heat flow provided by a deep-lying magma; (6) temperature of producing zone is 200°C. (392°F.); and (7) surface hydrothermal activity occurs as hot springs and steam jets of 100° to 190°C. (212° to 374°F.)

*Wairakei field, North Island, New Zealand,* was described by W. G. Grindley (1961) as a volcanic region 240 kilometers long, a Recent graben filled exclusively by volcanites. Two volcanoes are active at each end of the graben. The impervious Huka Formation is the controlling factor in heat accumulation. The producing aquifer is the Waiora Formation, a porous pumice breccia with buried flows of andesite in the lower part. Underlying the reservoir is the Wairakei Ignimbrite Formation, consisting of impervious dense ignimbrite sheets.

*The Geysers, California,* was described by McNitt (1963) as having Pleistocene and Pliocene volcanic vents, with rhyolite flows and tuffs, basaltic, dacitic, and andesitic lavas in outcrop in the hydrothermal area. The stratigraphic sequence consists of (1) Cretaceous, massive, yellow-brown sandstone and gray shale, 1,700–3,000 meters thick; (2) Knoxville Formation (Upper Jurassic), thin-bedded graywacke and shale, intruded by 150–300 meters of serpentine sills, thickness 1,700 meters; and (3) Franciscan Group (Upper Jurassic), interbedded graywacke and spilitic basalt, and small amounts of shale, conglomerate, and chert; intruded by serpentine sills; thickness, 9,000 meters. The Mesozoic rocks were folded gently, then intensely faulted. Surface thermal activity consists of hot springs, fumaroles, and hydrothermal rock alterations. The producing zone is a sandstone in the Franciscan, shattered severely by faulting, and altered by hydrothermal activity. The sandstone is dense, indurated, with some interbedded shale. Fractures to 0.5 inch wide have been cored. The BHT average is 208°C. (401°F.), pressure is 60 to 150 psi.

PICARD, M. DANE, Department of Geology, University of Nebraska, Lincoln, Nebr.

### Paleocurrents and Shoreline Orientations in Green River Formation (Eocene), Raven Ridge and Red Wash Areas, Northeastern Uinta Basin, Utah

Paleocurrent data from ripple marks and cross-stratification are related to orientations of shorelines and sandstone-body trends in the lacustrine and fluvial setting of the Green River Formation (Eocene). In the Red Wash field and the adjacent outcrops along Raven Ridge, northeastern margin of the Uinta basin, 125 paleocurrent directions were measured from cross-stratification and asymmetrical ripple marks in the Douglas Creek and Garden Gulch Members and the lower part of the Parachute Creek Member.

Vertical stratigraphic variation of paleocurrent directions at each locality is small, indicating that the over-all current system was stable. A plot of measurements of 84 asymmetric and 68 symmetric ripple marks shows that their distribution is very similar, which is interpreted to be the result of their formation by the same current system. Based on arcs of azimuths, there is essentially no difference between paleocurrent directions from cross-stratification and from ripple marks. The dominant paleocurrent directions are toward the north, south, and southeast. Of all observations, 25 per cent range from 331° to 30°, and 51 per cent range from 121° to 210°.

The shorelines in the northeastern Uinta basin area are interpreted to have been generally perpendicular to the dominant paleocurrent directions. Therefore, essentially all of the shorelines had bearings of 31° to 120°. An arc of 61° to 90° would contain about 40 per cent of the bearings of the shorelines, based on the paleocurrent data. Trends of single sandstone bodies, the total number of feet of sandstone, sandstone plus siltstone, and net sandstone in the Red Wash field, and the trends of major facies in the northeastern Uinta basin, support the generalizations about the orientations of shorelines and sandstone-body trends.

PILKEY, ORRIN H., Geology Department and Marine Laboratory, Duke University, Durham, N.C.

### Shoreline Processes

Shoreline can be considered to include the entire sedimentary regime encompassing the actively forming subaerial shore features, as well as the seaward extent of wave conditions capable of causing significant bottom disturbance. This offshore area corresponds to Dietz's "active surf lens," the seaward boundary of which commonly is at a 10-meter depth. The relatively narrow strip of the continent known as the shoreline is an area of extremely complex and variable sedimentation with highly variable morphology and sediment types. The importance attached to the understanding of shoreline processes by geologists is indicated by the large volume of literature concerned with this subject. In addition to being of interest to petroleum geologists because of the role of ancient shorelines as traps and reservoir rocks, the study of near-shore processes has immediate application toward solving the ever-growing shoreline engineering problems now being found along populated coasts.

The forces involved in shoreline processes are both subaerial and subaqueous and include wind, waves, tides, and chemical and biological agents. Important recent approaches to the study of these forces have been the quantitative works of Bagnold and Inman and the fluorescent grain-movement studies by Ingle and others.

Emphasis of the discussion of shoreline processes is on the Atlantic Coast of the United States between Cape Hatteras and Miami. Among other interesting aspects of this area is the particularly sharply defined "active surf lens," characterized by relatively fine grain size, in a "band"—usually less than 12 miles wide. Little sand-size material presently is being contributed by rivers and evidence is presented indicating that most shoreline sediment here, including beach and estuarine sand, is derived through winnowing and shoreward transport of central and outer-shelf material. The effect of varying wind and wave energies, tidal amplitudes, longshore current activities, and other factors is also exhibited along the southern Atlantic Coast of the United States.

PIPKIN, BERNARD W., 175 South Alvarado Street, Los Angeles, Calif.

### Mineralogy of 140-Foot Core from Willcox Playa, Cochise, Arizona

The Willcox basin in southeastern Arizona is a closed drainage system of approximately 1,600 square miles. A core, consisting almost entirely of black mud with a silt-clay ratio of 3:7, was recovered from the playa at the south end of the basin. The diagenetic environment of the core sediments is characterized by high pH (9.0–9.5) and negative Eh (—100 to —300 mv) values.

The dominant clay mineral is illite, with montmorillonite, mixed-layer illite-montmorillonite, and vermiculite in decreasing order of abundance. Two distinct monoionic divalent montmorillonite complexes occur with basal spacings of 14.2–14.7Å and 15.2–15.4Å, respectively. A moderately well-crystallized trioctahedral vermiculite occurs in about half of the core samples. Kaolinite and chlorite are present only in trace amounts, the kaolinite occurrences being restricted to the upper few feet of core. Comparison of the clay minerals of the core with those of the source area suggests that the former are of detrital origin.